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REMEDIATION OF THE FAULTLESS UNDERGROUND NUCLEAR TEST: MOVING FORWARD IN THE FACE OF MODEL UNCERTAINTY

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The hundreds of locations where nuclear tests were conducted underground are dramatic legacies of the cold war. The vast majority of these tests are within the borders of the Nevada Test Site (NTS), but 11 underground tests were conducted elsewhere. The Faultless test, conducted in central Nevada, is the site of an ongoing environmental remediation effort that has successfully progressed through numerous technical challenges due to close cooperation between the U.S. Department of Energy (DOE) National Nuclear Security Administration (NNSA) and the State of Nevada Division of Environmental Protection (NDEP). The challenges faced at this site are similar to those of many other sites of groundwater contamination: substantial uncertainties due to the relative lack of data from a highly heterogeneous subsurface environment. Knowing when, where, and how to devote the often enormous resources needed to collect new data is a common problem, and one that can cause disputes between remediators and regulators that stall progress toward closing sites. For Faultless, a variety of numerical modeling techniques and statistical tools were used to provide the information needed for NNSA and NDEP to confidently move forward along the remediation path to site closure.

A general framework for remediation was established in an agreement and consent order between DOE and the State of Nevada that recognized that no cost-effective technology currently exists to remove the source of the contaminants in the nuclear cavities. Rather, the emphasis of the corrective action is on identifying the impacted groundwater resource and ensuring protection of human health and the environment from the contamination through monitoring. As a result, groundwater flow and transport modeling is the lynchpin in the remediation effort.

The first step in the process was the development and approval of a Corrective Action Investigation Plan. This required several iterations, with the principal issue being whether or not new site data should be collected via drilling and testing. All parties eventually concluded that sufficient data existed to support the development of a flow and transport model for the site. The area around Faultless was intensively investigated in the 1960s as an alternative underground test area to the NTS, and as a result, data from 58 straddle packer tests were available to support the model.

The groundwater modeling was the next major step. Given the concerns regarding data adequacy, as well as the uncertainties inherent when addressing subsurface hydrogeology, a stochastic approach was employed. Sequential Indicator Simulation methods were used to generate hundreds of three-dimensional equiprobable maps of hydrogeologic units using geophysical and lithologic logs to define patterns of spatial correlation and as conditioning data. These maps were then populated with hydraulic conductivity values from the field tests using Sequential Gaussian

Simulation. These maps of subsurface hydrogeologic heterogeneity are used in the large-scale, three-dimensional numerical modeling of groundwater flow at the Faultless site. The groundwater velocity fields from the flow modeling are the basis for the transport calculations, which are performed using particle tracking methods. A variety of sensitivity analyses addressed parameter uncertainties. The conclusion of the modeling is that groundwater velocities around the Faultless test are low and transport of contaminants away from the nuclear cavity is very slow. Given the radioactive nature of the contaminants, this allows natural attenuation to be an effective remediation process.

Though the modeling approach was acceptable to NDEP, the regulator remained concerned about the uncertainties present in the analysis. The flow model incorporated uncertainty in the groundwater flow field due to spatial variability in hydraulic conductivity, but other sources of uncertainty were handled in a less rigorous manner. Lingering doubts about the adequacy of existing field data, combined with the need to demonstrate that an iterative process of data collection, analysis, and model refinement (if necessary) had been followed, prompted the regulator to require that additional analyses be performed. The ultimate question was whether new data collection would substantially reduce uncertainty. NNSA and NDEP agreed to perform a Data Decision Analysis (DDA) to analyze the effectiveness of potential data collection activities at reducing model uncertainty. This formed the third step in the process. After relating model input parameters to various field and laboratory efforts, an expert panel estimated the effectiveness of the potential activities at reducing uncertainty in the mean and range of the parameter values. The model was then re-run using the same Monte Carlo parameter sampling techniques for hundreds of realizations, but this time the selection was made from the modified (reduced uncertainty) parameter values estimated to result from the various data collection activities. The cost of these activities was also determined so that NNSA and NDEP were able to evaluate the cost required to achieve the calculated uncertainty reduction. The results of the DDA indicate that though there is large uncertainty present in some of the model parameters, the overall uncertainty in the calculated contaminant boundary (the metric of interest) during the 1,000-year regulatory timeframe is relatively small. As a result, though the various data collection activities would slightly reduce the uncertainty in the boundary, the significance of the reduction is minimal.

With the results of the flow and transport model and the rigorous uncertainty analysis of the DDA to evaluate possible improvements to the model, both NNSA and NDEP determined that the model was acceptable to move forward in the corrective action process. Key to this acceptance is acknowledgement that the model requires validation with independent data not used in its development. As all existing subsurface data were used in the modeling effort, it is apparent that this next step will require installation of new wells at the site. Drilling and testing in the remote valley where Faultless is located, with a groundwater table in excess of 200 m below land surface and a target depth for data collection at 1,000 m, is a costly and demanding effort. Through the careful evaluation of existing data and value of data collection, it may be possible to now maximize the return of the field effort and, rather than siting wells simply for characterization data, locate wells that will both validate the model and serve a future monitoring need. While planning begins for the validation and monitoring effort, the model will be used to calculate a contaminant boundary for the site so that NNSA and NDEP have a basis to begin their negotiations on site closure.